Doug Mahone
Pacific Gas & Electric Co
Heschong Mahone Group

Inclusion of Cool Roofs in Title 24

California Building Energy Efficiency Standards
Revisions for July 2003 Adoption

October 24, 2001

Description

The proposed measure promotes the use of cool, solar-reflective roofs to reduce cooling energy usage and peak electrical power demand in air-conditioned buildings (e.g., offices, retail stores, health care facilities, colleges and schools, refrigerated warehouses, high-tech manufacturing facilities) and increase thermal comfort in unconditioned buildings. Priority should be given to buildings located in climates with long cooling seasons and short heating seasons, particularly buildings with (a) poorly insulated roof systems; (b) distribution ducts in the attic; (c) cool-coatable distribution ducts on the roof; and/or (d) low rates of attic or plenum ventilation. In addition, using cool roofing materials in re-roofing applications in existing buildings can yield significant savings for buildings with older, inefficient air conditioning equipment.

Benefits

Cool roofs affect the energy use of a building in three ways:

1. During summer daytime, cool roofs reduce the heat conduction through the roof and hence reduce air-conditioning energy use.
2. During sunny cold winter days, cool roofs may cause an increase in heating energy consumption. In many California climate zones, potential heating penalties are a small fraction of cooling-energy savings in areas with long cooling seasons and short heating seasons.
3. In hot climates, the HVAC systems are designed to meet the cooling loads during summer peak conditions. Cool roofs will reduce the cooling load and the necessary HVAC system size. Since smaller HVAC systems run more efficiently year-round, cool roofs can potentially reduce electricity use by the air handling system in both summer and winter.

Commercial buildings are typically cooled in daytime when the sun is shining, while heating is typically needed in the dim early morning hours. Thus, cool roofs are very effective in reducing the summer electricity use with minimal impact on winter heating. In general, savings in annual net cooling and heating costs can be expected below latitude 40°N, and a reduction in summertime peak demand can be expected anywhere air conditioning is used. As a significant portion of the energy savings is realized during peak hours, time dependent valuation is likely to increase the cost-effectiveness of cool roof applications.

The peak temperature of the roof surface and system will be lowered, reducing diurnal thermal expansion and contraction of the surface material and degradation of subsurface insulation. The longer life of roofing materials may reduce maintenance and re-roofing costs. Improved thermal comfort will occur in zones of a building that are not conditioned (e.g., attic, plenum, storage areas).

Environmental Impact

No significant negative environmental impacts are expected if cool roofs are installed in the course of either new construction or regularly scheduled roof replacement (e.g., once every 10-25 years.) Small quantities of water and detergent may be used in cases where annual roof cleaning is required to maintain high reflectance. Cool roofs may last longer than warm roofs, reducing waste. Cool roofs also transfer less heat to the air than do warm roofs, and can help mitigate urban heat island effects. The resulting lower air temperatures can slow urban smog formation and increase human comfort both outdoors and in unconditioned buildings.

Type of Change

The proposed change will add a prescriptive requirement establishing a minimum reflectivity and emittance for each climate zone, specifically targeting those zones dominated by cooling energy use. By establishing this minimum value, overall envelope and performance approach calculations could result in compliance credits or penalties, depending on the product performance rating relative to the minimum requirement. In addition, the proposal may include recommendations for modifying the compliance calculation algorithms and assumptions to more accurately reflect the effects of cool roofs in the DOE-2.1E calculation engine.

The proposed change will result in modification to all three envelope compliance options, as well as revisions to the Standards, nonresidential ACM manual, and compliance forms to reflect the changes described below.

1. **Prescriptive Compliance**. Adopt options for roofs solar reflectance and emittance for each climate region. This would expand the list of prescriptive envelope requirements, since the 2001 revisions to Title 24 do not address reflective roofs in the prescriptive compliance approach.
2. **Performance Compliance**. The 2001 revisions allow the inclusion of reflective roofs as a compliance option for credit. The current proposal will use the newly established prescriptive requirements to determine the energy budget for performance compliance calculations, resulting in potential compliance credits or penalties. In addition, the ACM will be modified to include an input for emittance.
3. **Overall Envelope Approach**. The standard heat gain equation will reference the applicable values from the Prescriptive Envelope Criteria tables (Tables 1-H or 1-I in the 2001 Standards) to determine the value for the standard building roof absorptivity and emittance. Currently, the equations use a constant value of 0.7 for absorptivity and do not address emittance. The proposed heat gain equation will use the Cool Roof Rating Council certified values for absorptivity and emittance.

Measure Availability and Cost

Cool options for built-up roofing (BUR) and modified bitumen roofing include use of light-colored aggregates or granules, and use of non-metallic reflective coatings. Options for single-ply membranes and metal roofs include the use of factory-made (or painted) white materials. The lion’s share (59%) of the roofing market goes to BUR and modified bitumen. There are many manufacturers of each type of cool roofing product. The EPA cool roof program lists approximately 175 Roof Product Partners on their web site. The EPA program allows manufacturers to self-certify their products’ performance criteria and does not include a minimum emittance requirement for eligible roofing products. It is likely that some fraction of these manufacturers and their associated products will not meet the performance requirements for cool roofs defined in the 2001 Standards, but it is reasonable to assume that many will, thus an ample supply of eligible products will be readily available.

The choice of cool roofs for new buildings typically incur minimal (and in some cases no) additional costs (for existing buildings the incremental cost is also minimal if changes are incorporated into routine re-roofing schedules). Several experiments on individual buildings in California and Florida show that painting roofs white reduces air conditioning load by 10-50% (corresponding to savings of \$10-100 per year per 100 m^2), depending on the thickness of insulation under the roof. Savings depend on the thermal integrity of a building and on climate conditions.

Useful Life, Persistence and Maintenance

Roof reflectivity of cool roofing materials may change over time due to aging, weathering, and soiling. The building owner should require a warranty stating that after five years the cool material will remain in place and retain at least 70% of its initial reflectivity. Regular cleaning can mitigate the effects of soiling.

Performance Verification

Application of cool roofing products does not require performance verification or commissioning to ensure that the material performance is achieved. Installers must adhere to the manufacturer's installation instructions and the mandatory requirements for cool roofs defined in Section 118 (f) of the 2001 Standards. Manufacturers will certify and label their products through the process described in Section 10-113 of the 2001 Standards.

ASHRAE Standard 90.1 (non-residential buildings) recommends a minimum initial solar reflectance of 70%. ASHRAE Standard 90.2 (residential buildings) recommends a minimum initial solar reflectance of 65% and a minimum initial thermal emittance of 80%, ***or*** a minimum initial Solar Reflectance Index (SRI) of 75. [SRI combines the effects of solar reflectance and thermal emittance. For a reference black with a solar reflectance of 5% and a thermal emittance of 90%, the SRI is defined as 0; for a reference white with 80% reflectance and 90% emittance, the SRI is defined as 100.]

ASTM Standard E 903 and/or the Devices & Services Solar Spectrum Reflectometer can be used to measure reflectivity in the lab. ASTM Standard E 1918 is designed to measure reflectivity in the field. Thermal emittance can be measured with ASTM standard E 408 or C 1371. Measurements of the thermal emittance may not be necessary if one excludes metals (galvanized roofing, aluminum roofing, unpainted metals, metallic roof coatings) from the list of cool materials.

Cost Effectiveness

In general, the proposed change is likely to be cost effective below the 40^{th} parallel for most residential and commercial buildings, depending upon building design. Cost effectiveness can be estimated by quantifying the following parameters:

1. annual cooling electricity savings
2. annual heating electricity and gas deficit
3. peak cooling electricity demand reduction
4. time-dependent valuation (TDV) of energy savings
5. participation in other energy efficiency and load curtailment programs-
6. savings in material and labor costs from a potential extended life of roof surface There may be a potential maintenance cost for buildings that may need to wash the roof to maintain their high-solar reflectance.
7. cost differential of reflective roof system as compared to base-line roof system (expenditure decrease from participation in reflective roof rebate program, or other available incentive programs)

Analysis Tools

The building energy simulation program DOE-2.1E will be the primary analysis tool to quantify energy savings and peak demand. It is also useful to benchmark DOE-2 simulations against a more state-of-the-art model such as EnergyPlus to determine whether changes to the current algorithms should be implemented to more accurately model the effects of cool roofs.

Relationship to Other Measures

The optimal level of roof insulation is a function of roof reflectivity.

Bibliography and Other Research

Energy savings from the use of solar-reflective roofs have been predicted through computer simulations and verified with measured data in both residential and commercial buildings.

Studies using computer simulations to estimate the impact of solar-reflective roofs include Konopacki and Akbari (2000 and 1998), Konopacki ***et al***. (1997), Akbari ***et al***. (1998), Parker ***et al***. (1998a) and Gartland ***et al***. (1996).

Several field studies have documented measured air-conditioning summertime energy savings that result from the use of solar-reflective roof systems. These studies were conducted on residential and commercial buildings in warm weather climates, mostly in Florida and California. In a recent study, Konopacki and Akbari (2001) have estimated daily energy savings of 3.6 Wh/ft^2 (11%) and peak power reduction of 0.35 W/ft^2 (14%) in a large retail store in Austin from the application of a reflective membrane. Akbari and Rainer (2000) measured daily a/c energy savings of 3.1 Wh/ft^2 (1%) in two Nevada telecommunication regeneration buildings. Konopacki ***et al***. (1998) have demonstrated the impact of reflective roofs in three California commercial buildings, two medical offices and one retail store, measuring summertime daily a/c savings of 6.3, 3.6 and 0.4 Wh/ft^2 (18, 13 and 2%) and demand reduction of 0.31, 0.22 and 0.15 W/ft^2 (12, 8 and 9%). Akbari ***et al***. (1997a) have shown in one monitored Sacramento house summertime daily cooling energy savings of 1.3 Wh/ft^2 (63%) and peak power reduction of 0.33 W/ft^2 (25%), and, in a Sacramento school bungalow, cooling energy savings of 4.4 Wh/ft^2 (46%) and peak power reduction of 0.63 W/ft^2 (20%) from an increase in roof reflectance. Hildebrandt ***et al***. (1998) measured daily a/c savings of 0.9, 1.9 and 1.0 Wh/ft^2 (17, 26 and 39%) in an office, a museum and a hospice with reflective roofs in Sacramento. Parker ***et al***. (1998a) have monitored the performance of reflective roofs in 11 Florida residences with daily savings ranging from 0.5-12.7 Wh/ft^2 (2-43%) and peak demand reduction of 0.14-0.72 W/ft^2 (12-28%). Parker ***et al***. (1999) measured daily energy savings of 17% from a reflective roof in a high-efficiency home in Florida. Parker ***et al***. (1997) have also monitored seven retail stores within a strip mall in Florida before and after applying a reflective roof coating and measured a 0.7 Wh/ft^2 (25%) drop in summertime daily cooling energy use and a 0.06 W/ft^2 (29%) decrease in demand. Parker ***et al***. (1998b) measured daily energy savings of 4.1 Wh/ft^2 (25%) and peak power reduction of 0.56 W/ft^2 (30%) from a reflective roof on a school building in Florida. Akridge (1998) reported daily savings of 7.0 Wh/ft^2 (28%) for an education building in Georgia, which had an unpainted galvanized roof coated with white acrylic. An office building in southern Mississippi was shown to save 22% after the application of a reflective roof coating (Boutwell and Salinas 1986).

References (Simulations)

Akbari, H., S. Konopacki, C. Eley, B. Wilcox, M. Van Geem and D. Parker. 1998. "Calculations for Reflective Roofs in Support of Standard 90.1". ***ASHRAE Transactions*** **104**(1):984-995.

Gartland, L., S. Konopacki and H. Akbari. 1996." Modeling the Effects of Reflective Roofing". ***ACEEE Summer Study on Energy Efficiency in Buildings*** **4**:117-124. Pacific Grove, CA.

Konopacki, S. and H. Akbari. 2000. "Energy Savings Calculations for Heat Island Reduction Strategies in Baton Rouge, Sacramento and Salt Lake City". Lawrence Berkeley National Laboratory Report LBNL-42890. Berkeley, CA.

Konopacki, S. and H. Akbari. 1998. "Simulated Impact of Roof Surface Solar Absorptance, Attic, and Duct Insulation on Cooling and Heating Energy Use in Single-Family New Residential Buildings". Lawrence Berkeley National Laboratory Report LBNL-41834. Berkeley, CA.

Konopacki, S., H. Akbari, M. Pomerantz, S. Gabersek and L. Gartland. 1997. "Cooling Energy Savings Potential of Light-Colored Roofs for Residential and Commercial Buildings in 11 US Metropolitan Areas". Lawrence Berkeley National Laboratory Report LBNL-39433. Berkeley, CA.

Parker, D., J. Huang, S. Konopacki, L. Gartland, J. Sherwin and L. Gu. 1998a. "Measured and Simulated Performance of Reflective Roofing Systems in Residential Buildings". ***ASHRAE Transactions*** **104**(1):963-975.

References (Measurements)

Akbari, H., S. Bretz, D. Kurn and J. Hanford. 1997a. "Peak Power and Cooling Energy Savings of High-Albedo Roofs". ***Energy and Buildings*** **25**:117-126.

Akbari, H. and L. Rainer. 2000. "Measured Energy Savings from the Application of Reflective Roofs in 3 AT&T Regeneration Buildings". Lawrence Berkeley National Laboratory Report LBNL-47075. Berkeley, CA.

Akridge, J. 1998. "High-Albedo Roof Coatings - Impact on Energy Consumption". ***ASHRAE Technical Data Bulletin*** **14**(2).

Boutwell, C. and Y. Salinas. 1986. "Building for the Future - Phase I: An Energy Saving Materials Research Project". Oxford: Mississippi Power Co., Rohm and Haas Co. and the University of Mississippi.

Hildebrandt, E., W. Bos and R. Moore. 1998." Assessing the Impacts of White Roofs on Building Energy Loads" ***ASHRAE Technical Data Bulletin*** **14**(2).

Konopacki, S. and H. Akbari. 2001. "Measured Energy Savings and Demand Reduction from a Reflective Roof Membrane on a Large Retail Store in Austin". Lawrence Berkeley National Laboratory Report LBNL-47149. Berkeley, CA.

Konopacki, S., H. Akbari, L. Gartland and L. Rainer. 1998. "Demonstration of Energy Savings of Cool Roofs". Lawrence Berkeley National Laboratory Report LBNL-40673. Berkeley, CA.

Parker, D., J. Huang, S. Konopacki, L. Gartland, J. Sherwin and L. Gu. 1998a. "Measured and Simulated Performance of Reflective Roofing Systems in Residential Buildings". ***ASHRAE Transactions*** **104**(1):963-975.

Parker, D. and K. Sheinkopf. 1999. "Cool Home Features Bring Peak Energy Savings". ***Home Energy*** **16**:22-27.

Parker, D., J. Sherwin and J. Sonne. 1998b. "Measured Performance of a Reflective Roofing System in a Florida Commercial Building". ***ASHRAE Technical Data Bulletin*** **14**(2).

Parker, D., J. Sonne and J. Sherwin. 1997. "Demonstration of Cooling Savings of Light Colored Roof Surfacing in Florida Commercial Buildings: Retail Strip Mall". Florida Solar Energy Center Report FSEC-CR-964-97. Cocoa, FL.